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Properties of high-z galaxies as seen through lensing clusters

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Abstract. We discuss the first results obtained on the study of a sample of high-z galaxies ($2 \lesssim z \lesssim 7$), using the gravitational amplification effect in the core of lensing clusters. Sources are located close to the critical lines in clusters with well constrained mass distributions, and selected through photometric redshifts, computed on a large wavelength domain, and lens inversion techniques.

1. Introduction

The basis of our large collaboration program, involving different european institutions, is to use clusters of galaxies as gravitational lenses to build up and to study an independent sample of high-z galaxies. This sample is important because it complements the large samples obtained in field surveys. The idea is to take benefit from the large amplification factor close to the critical lines in lensing clusters (typically 1 to 3 magnitudes) to study the properties of the dis-

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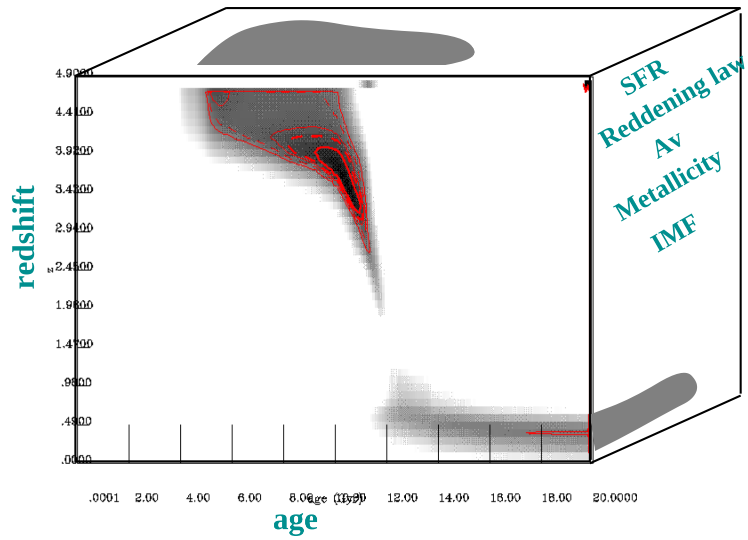

Figure 1. An artist view of the SED fitting procedure to compute z_{phot}

tant background population of lensed galaxies. The signal/noise ratio in spectra of amplified sources and the detection fluxes are improved beyond the limits of conventional techniques, whatever the wavelength used for this exercise. In particular, the amplification properties have been succesfully used in the ultra-deep MIR survey of A2390 (Altieri et al. 1999), and the SCUBA cluster lens-survey (Smail et al 98; Blain et al. 99). This collaboration program is presently going on, and the next step is to perform the spectroscopic follow up (mainly with the VLT) on a sample of high-z candidates selected through both photometric redshifts and lensing inversion procedures.

Number of high-z lensed galaxies have been found since the first case of lensed galaxy at $z \gtrsim 2$, the spectacular blue arc in Cl2244-02 (Mellier et al. 1991), and these findings strongly encourage our approach. Among the recent examples of highly-magnified distant galaxies, identified either purposely or serendipitously, one can mention: the star-forming source #384 in A2218 at z=2.51 (Ebbels et al. 1996); the luminous z=2.7 arc behind the EMSS cluster MS1512+36 (Yee et al. 1996; Seitz et al. 1998); the three z $\sim$ 4 galaxies in Cl0939+47 (Trager et al. 1997); a z=4.92 system in Cl1358+62 (Franx et al. 1997, Soifer et al. 1998); and the two red galaxies at $z \sim 4$ in A2390 (Frye & Broadhurst 1998, Pelló et al. 1999).

2. The photometric redshift approach

Photometric redshifts (hereafter z_{phot}) are computed using a standard SED fitting procedure originally developed by Miralles (1998). A new public version of this tool, called *hyperz*, is presently under developement (Bolzonella, Miralles and Pelló, in preparation; see also Bolzonella & Pelló, this conference). The set of templates includes mainly spectra from the Bruzual & Charlot evolutionary code (GISSEL98, Bruzual & Charlot 1993), and also a set of empirical SEDs compiled

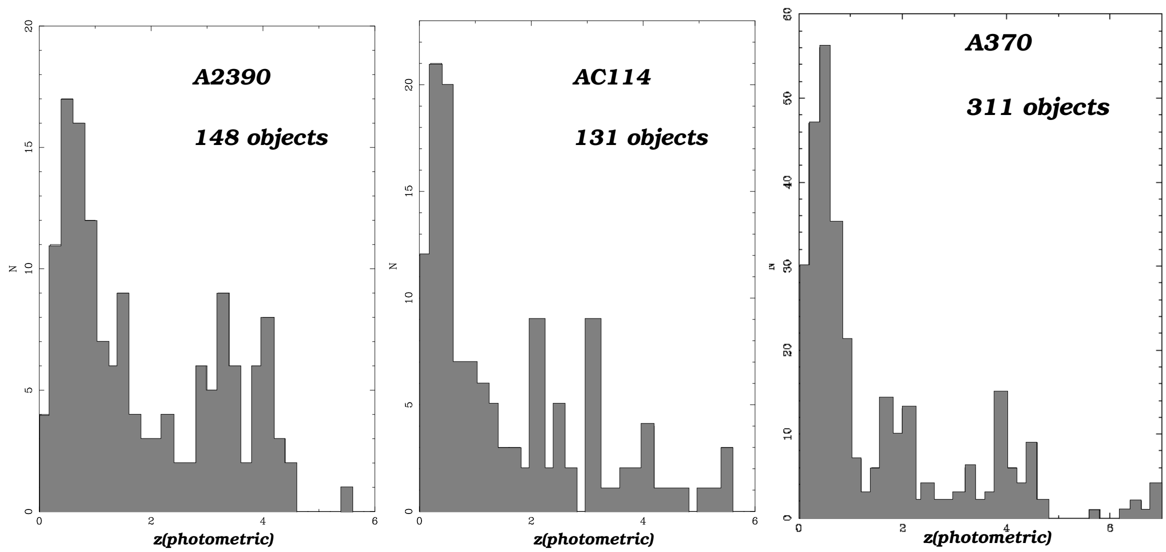

Figure 2. z_{phot} distribution of arclets in A2390 (right), AC114 and A370 (left), obtained with *hyperz*. In A2390, selection criteria are based on the morphology of the WFPC2 images (elongation, orientation and surface brightness); in A370, only a photometric selection was applied, aimed to avoid the obvious bright cluster members; in AC114, all objects within a 1.5 arcmin aperture from the center are displayed.

by Coleman, Wu and Weedman (1980) to represent the local population of galaxies. The synthetic database derived from Bruzual & Charlot includes 255 spectra, distributed into 5 different star-formation regimes (all of them with solar metallicity): a burst of 0.1 Gyr, a constant star-formation rate, and 3 μ models (exponential-decaying SFR) with characteristic times of star-formation chosen to match the present-day sequence of E, Sa and Sc galaxies. The reddening law is taken from Calzetti (1997), with A_V ranging between 0 and 0.5 magnitudes. Flux decrements in the Lyman forest are computed according to Madau (1995). When applying *hyperz* to the spectroscopic samples available on the HDF, the uncertainties are typically $\delta z/(1+z) \sim 0.1$ (Bolzonella & Pelló, this conference).

3. Results and Future Developments

High-z lensed sources with $z_{phot} \geq 2$ are selected close to the appropriate critical lines. In all cases, z_{phot} are computed from broad-band photometry on a large wavelength interval, from B (U when possible) to K. This allows to cancel the biases which focus the convergence of the fitting procedure towards or against a particular type of galaxy or redshift domain, and also to reduce the errors on z_{phot}. Furthermore, it permits to optimize the instrument choice for further spectroscopic follow-up (visible vs. near-IR bands). The first spectroscopic surveys were performed on $\sim$ 4m telescopes: CFHT/ WHT/ ESO (3.6m, NTT) (Toulouse/Cambridge/Paris/Barcelona collaboration). They have

demonstrated the efficiency of the technique (see for instance Ebbels et al. 1996, 1998, and Pelló et al. 1999). The present large VLT Program is focused on an X-ray selected sample of 12 lensing clusters. Photometry was performed on $\sim$ 4m telescopes (NTT, 3.6m telescope ESO, ...), including HST and/or other archive images when available. We intend to obtain the whole spectroscopic follow up at VLT (FORS, ISAAC, ...). The main goals of this program are: to determine the z distribution of a very faint subsample of high-z lensed galaxies, unvisible otherwise; to study the SED of $z \geq 1$ galaxies (especially $z \geq 2$) for a sample less biased in luminosity than the field (SFR history, permitted region in the age-metallicity- reddening-... space) and to explore the dynamics of $z \geq 2$ sources by using 2D spectroscopy of arcs, a prospective issue for future studies.

Most of the photometric survey is presently completed. We have obtained the (photometric) z distribution of arclets in several well known clusters (A2390, A370, Cl2244-02, AC114,...). Figure 2 displays the z_{phot} distribution of arclets in three fields, where the samples were defined according to different criteria. The typical number of high-z sources found in the inner 1' radius region of the cluster is $\sim$ 30 to 50 at $1 \leq z \leq 7$. For a subsample of spectroscopically confirmed sources in different clusters (with $0.4 \leq z \leq 4$), the z_{phot} accuracy has been checked as a function of the relevant parameters (SFR, reddening, age and metallicity of the stellar population). We have also cross-checked the consistency between the photometric, the spectroscopic and the lensing redshift obtained from inversion methods (Ebbels et al. 1998). According to the present results, the agreement between the three methods is good up to at least $z \lesssim 1.5$. The comparison between the spectroscopic and the lensing redshift was already studied in the field of A2218 (Ebbels et al. 1998), and all the present results seem to follow this trend up to $z \lesssim 1.5$ at least. Taking into account that z_{phot} and lensing inversion techniques produce independent probability distributions for amplified sources, combining both methods provides with a robust way to determine the redshift distribution of distant sources. This comparison gives promising results at $z \gtrsim 1.5$, for the most amplified sources, but an enlarged spectroscopic sample is urgently needed to conclude, in particular for the most distant candidates which could be the most distant galaxies ever detected.

The method is restricted to lensing clusters whose mass distribution is highly constrained by multiple images (revealed by HST or ground-based multicolor images), where the amplification uncertainties are typically $\Delta m_{lensing} <$ 0.3 magnitudes. Such well constrained mass distributions enable to recover precisely the properties of lensed galaxies (morphology, magnification factor). It is worth to note that highly magnified sources are presently the only way to access the dynamical properties of galaxies at $z \geq 2$, through 2D spectroscopy, at a spatial resolution $\sim$ 1 kpc. The two multiple-images at the same $z \sim 4$, observed behind A2390, are un example of these reconstruction capabilities (Pelló et al. 1999). Thanks to the lensing inversion, lensing clusters can therefore be used to calibrate photometric redshifts as well, up to the faintest limits in magnitude for a given z. They could be also used advantageously to search for primeval galaxies, in order to put strong constraints on the scenarios of galaxy formation.

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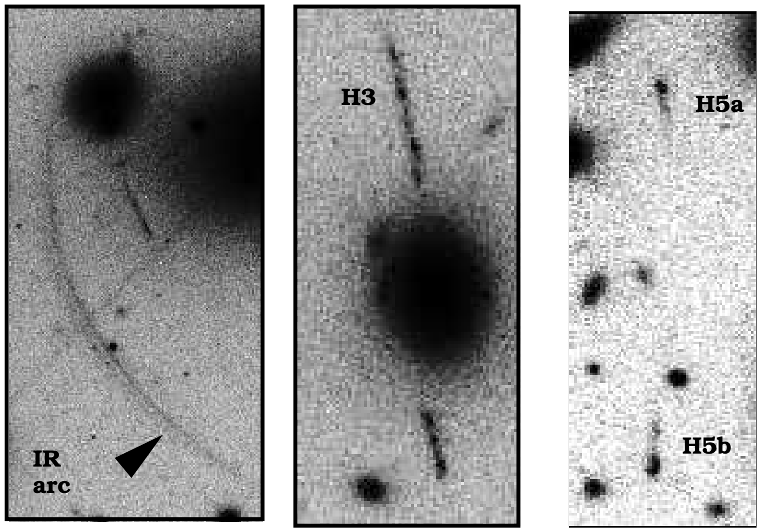

Figure 3. Several multiple images at $z \geq 1$ in A2390, displayed in the I band (WFPC2).

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